Physical Properties of Preserved Core From The Geysers Scientific Corehole, SB-15D
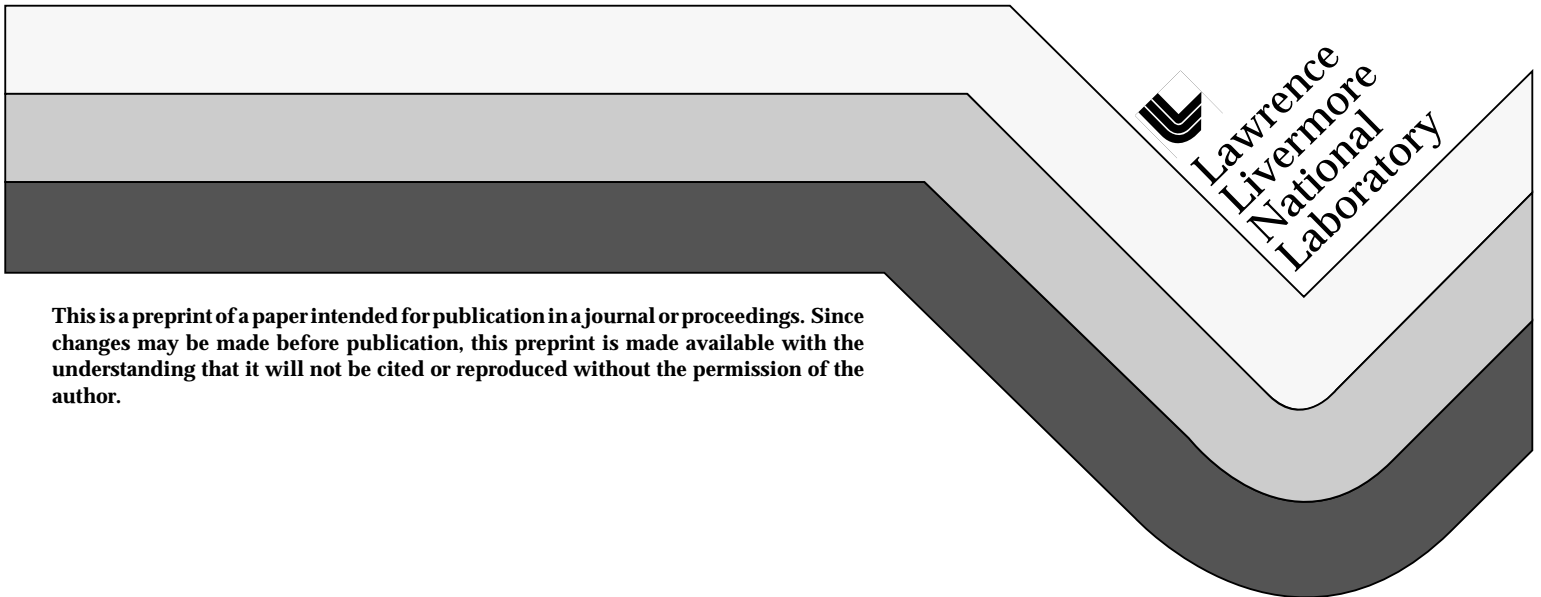
J. Roberts
B.P. Bonner
A.G. Duba
D.L. Schneberk

January 1996

Lawrence Livermore National Laboratory

PHYSICAL PROPERTIES OF PRESERVED CORE
FROM THE GEYSERS SCIENTIFIC COREHOLE, SB-15D

J. J. Roberts[†], B. P. Bonner[†], A. G. Duba[†], and D. L Schneberk[‡]

[†]Experimental Geophysics Group, MS L-201
[‡]Nondestructive Evaluation Section
Lawrence Livermore National Laboratory
Livermore, CA 94550

ABSTRACT

X-ray attenuation, electrical conductivity, and ultrasonic velocity are reported for a segment of preserved core from SB-15D, 918 ft. X-ray tomography and ultrasonic measurements change as the core dries, providing information regarding handling and disturbance of the core. Electrical conductivity measurements at reservoir conditions indicate that pore fluid properties and pore microstructure control bulk conductivity. These data are useful for calibration and interpretation of field geophysical measurements.

INTRODUCTION

Approximately 800 ft of continuous core was recovered from borehole SB-15D (near the site of the abandoned Geysers Resort) during a DOE drilling operation conducted in September 1994. Sections of core were collected at 50 ft intervals and preserved in capped aluminum tubes to minimize drying and disturbance of the core. In order to improve understanding of water content, storage and distribution in the reservoir, measurements of physical properties are now underway for a section of the preserved core, collected during coring run 12 at 918 ft. Water content of the preserved core is necessary input for predictions of reservoir performance and lifetime and for calibrating indirect measurements of pore fluid distribution in the field by geophysical methods.

Various mechanical and electrical measurements, all sensitive to different aspects of the problem of water content and storage, are reported here. Ultrasonic compressional velocity and weight loss were measured during drying of whole core to determine core degradation and to bound the seismic velocity decreases observed in the field associated with reservoir production. Velocity measurements provide extremely sensitive indications of cracking.

Compressional velocity is strongly dependent on water content near full saturation when porosity is in the form of thin cracks. The electrical conductivity of plugs removed from the core and saturated with brine was measured at elevated temperature and pressure. Electrical conductivity is most sensitive to pore fluid properties and configuration and may provide a means of measuring the effect of capillarity on the steam transition for in-situ conditions. Measurements of electrical conductivity are also needed to calibrate field electrical measurements. Three dimensional x-ray scans were used to track water distribution and to provide detailed observations of structural changes caused by drying. The potential of using statistical analysis of x-ray attenuation data to compute water content from x-ray tomographs was addressed by a series of scans made during dry out and resaturation of a segment of whole core. The long term objective is to determine water content as a function of depth in the borehole and to evaluate the effect of drilling on measured water contents. These material properties are also useful for interpreting seismic and electrical measurements at The Geysers.

X-RAY TOMOGRAPHY

Experimental. The third generation x-ray scanning device and image reconstruction procedures used to examine Geysers samples have been described by Bonner et al. (1994). One important modification, the substitution of a 110 mm diameter bundle scintillator constructed of 10 micrometer glass fibers for the scintillator plate, is now used to detect transmitted x-rays. Image contrast has been improved significantly.

Results. Periodic scans of segments of the preserved core, still in the aluminum tubes, have been made since drilling. Preliminary analysis of the images show that the pore fluid has migrated in response to capillary forces. Earlier work has demonstrated that quantitative

Fig. 1. Radial x-ray tomographs of run 12,918 ft depth. Core is ~3.4 inches in diameter. Brighter regions indicate higher x-ray attenuation, darker areas less x-ray attenuation. Pixel size is 110 μm. The outer ring is the aluminum core tube. Sample was removed from tube, dried, resaturated and dried. a) Image of dry core. b) Image of resaturated core. Note that the dry image shows dark, linear features suggestive of cracks. This could explain lower acoustic velocities in the dry core. The resaturated image does not show the cracks, indicating that they are either water filled and undetectable or contain clays that have resaturated and healed the fractures.

measurement of water saturation in low porosity rocks such as graywacke and argillite from The Geysers requires careful calibration and precise relocation of repeated scans (Bonner et al., 1994, 1995). The contrast resolution of the x-ray attenuation measurements (0.2%) is sufficient to detect changes in density caused by changes in water content, if sample heterogeneity can be taken into account. A series of repeated scans of a segment of the 918 ft. core were performed to determine if useful estimates of water content are feasible for these cores. This core segment, which was also used for ultrasonic measurements, was scanned after drying and then after re-impregnation with tap water to nearly full saturation. Radial computed tomographic (CT) slices of the core at nearly the same elevation before and after saturation are given in Figure 1a,b. These slices are quite homogeneous in comparison to other sections of scanned SB-15D core (Bonner et al, 1995). Average attenuation for 50 vertically stacked areas (50x50 pixels on a side, ~36 mm2) which were selected to avoid veins and selvage, are presented as Figure 2. Both curves have a central peak, reflecting subtle changes in mineralogy at this scale. The attenuation of the saturated sample is uniformly higher than the dry sample. Relatively minor changes in the shape of the curve suggests that the imbibition was uniform. The averaging procedure is robust, reducing the fluctuation in attenuation caused by local heterogeneity to a much lower level than the change caused by imbibition of tap water into this core, which has a bulk porosity of ~5%. With good relocation, it should be possible to estimate water content from tomographs taken promptly after drilling.
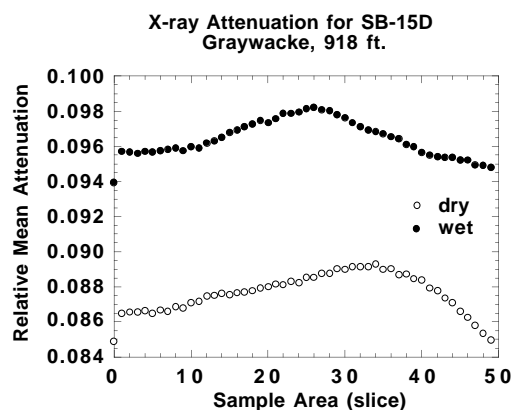

Fig. 2. Plot of relative mean x-ray attenuation for dry and wet samples of SB-15D, run 12, 918 ft. A 50x50 pixel region was selected, and the mean attenuation calculated for 50 different depths (slices). Dry sample displays a similar shape curve compared to that of the wet sample, but lower attenuation than the resaturated case.

ULTRASONIC MEASUREMENTS

Experimental. Ultrasonic velocity was measured across the diameter of core after removal from the aluminum sleeve using a variation of the pulse transmission method (Sears and Bonner, 1981). First attempts to obtain compressional velocities were unsuccessful because the standard methods in use for rocks, plane wave propagation at frequencies above 300 kHz, could not penetrate the ~100 mm diameter core. A low frequency ultrasonic method, adapted from the nondestructive evaluation of concrete, was developed for these measurements. An exponential horn was used to focus 40 kHz energy into the sample and the transmitted signal was detected with a 100 kHz contact transducer. Arrivals were digitized and averaged to improve the signal to noise ratio.

Results. When the 918 ft. core was removed from the aluminum sleeve, weights and velocities were monitored for over thirty days. The first reliable velocity obtained was 3.97 km/s, somewhat lower than that reported for small plugs by Boitnott and Boyd (this volume). Direct comparison is difficult because experimental problems discussed above caused a 24 hour delay in obtaining data. Measurements across several diameters demonstrated that the propagation paths are heterogeneous at the core scale. The values reported here are for the highest quality, fastest, arrivals. Signals were highly attenuated in specific directions; this effect will be investigated in detail later. Heterogeneity in wave velocity and attenuation increased during drying, and surface cracks began to appear as drying proceeded.

The drying history for graywacke from 918 ft. is plotted along with velocity measurements in Figure 3. Only a few velocity measurements were taken, because the ultrasonic coupling gel migrated into the core due to capillary forces, potentially biasing the weight and velocity measurement. After the initial dryout, the core segment was evacuated in a vacuum chamber and backfilled with tap water to estimate the connected porosity from the increase in weight. The core volume was estimated by fluid displacement. The porosity was determined to be 4.5 - 5%, which is in the range reported by Gunderson (1990) for whole core measurements at The Geysers. The total water content was estimated by weighing after drying and after re-saturating (to near 100%). The initial weight of the core upon removal from the aluminum tube indicates a saturation of near 80%, which includes any fluid taken up by the core during drilling. The velocity measured after the first drying cycle and subsequent resaturation (to ~95% water saturation) is 3.75 km/s. This velocity is lower

than that observed at ~80% saturation at the beginning of the first drying cycle, suggesting that structural damage has occurred during drying. This effect is known and expected for shale and other clay rich rocks, but is somewhat surprising for graywacke with minor clay content. Strategic placement of the clay fraction along filled fractures could account for this behavior.

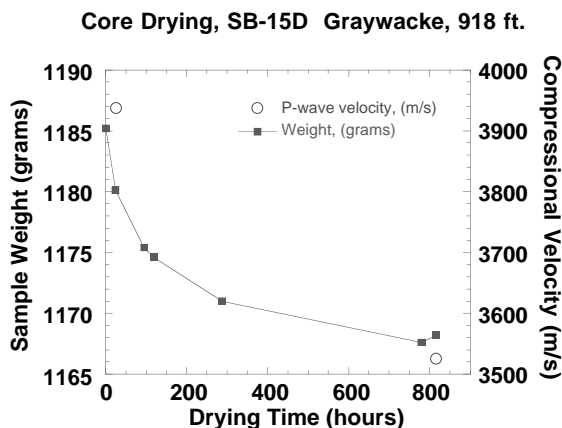### Core Drying, SB-15D Graywacke, 918 ft.

Fig. 3. Drying history of core sample. Sample weight is shown as a function of drying time, along with two determinations of the P-wave velocity. Drying continued for more than a month.

ELECTRICAL MEASUREMENTS

Experimental. Samples of preserved core from SB-15D were prepared by machining right cylinders approximately 1.5 cm high and 2.5 cm diameter. Porosity was determined by drying the samples, weighing, then evacuating the samples and backfilling with water under pressure. When a steady weight was obtained it was assumed the samples were saturated. The porosity is determined by subtracting the dry density from the wet density. Porosity varied between 1 and 6.5% with a mean of 3.7% for twelve samples. Prior to electrical conductivity measurements, samples were saturated in a brine solution consisting of distilled water with 1.87 g NaCl/liter. The conductivity of the solution is 3.74 mS/cm. Samples were then jacketed in viton with Hastalloy endcaps backed by a perforated Pt foil electrode. The endcaps contained a chamber that acted as a reservoir for water exiting the sample upon pressurization. Three or four samples were simultaneously placed inside the externally-heated pressure vessel which used isopar fluid as the pressurization medium. Electrical leads exited the vessel through coned seals in the vessel head. An HP 4274A LCR meter was used to measure the resistance and capacitance of the samples between 100 and 2000 Hz. All data were collected and stored via computer including pressure and temperature measurements.

Electrical Conductivity of Preserved SB-15D Samples as a Function of Temperature
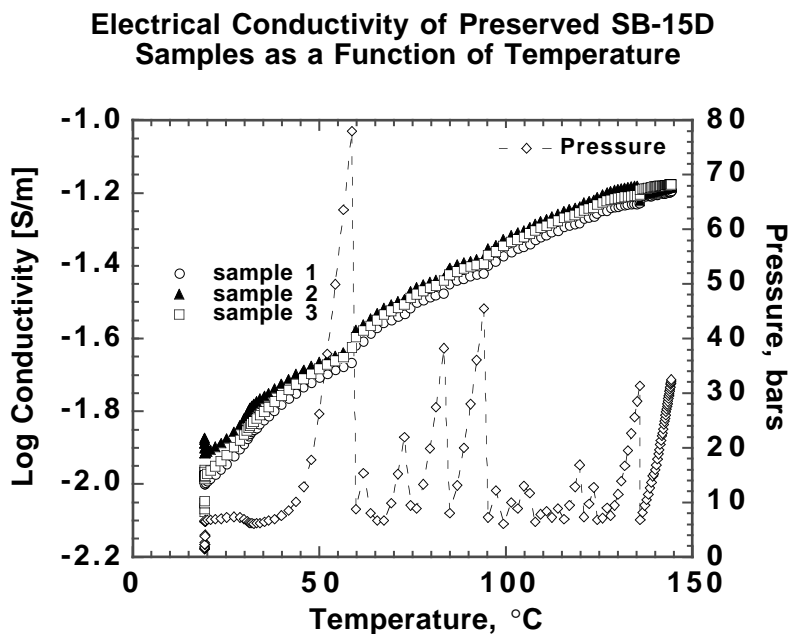
Fig. 4. Plot of log conductivity (S/m) as a function of temperature for three samples. Confining pressure is shown on the second y-axis. Pressure was manually controlled and needed to be reduced as temperature increased. A strong temperature dependence which correlates with the temperature dependence of pore fluid conductivity is observed. Increasing pressure decreases total electrical conductivity but is a secondary effect (see text).

Results. Measurements began on samples at room temperature (~21°C) and ~3 bars pressure. The conductivity values for three samples ranged between $10^{-1.85}$ and $10^{-2.05}$ S/m (Fig. 4). Increasing pressure had only a small effect in the electrical conductivity. An increase in pressure up to ~90 bars decreased the conductivity by ~0.05 log units. Increasing temperature had a large effect on the electrical conductivity of all samples. At a pressure of ~10 bars, increasing temperature from 20 to 145°C resulted in an increase in the electrical conductivity of ~0.8 log units (from ~10^{-2} to $10^{-1.2}$ S/m).

Lowering the pressure when the samples were at temperatures of ~145°C produced some interesting effects. Although the pore pressure was not controlled explicitly, lowering the confining pressure lowered the pore pressure enough so that the steam field was entered. At 145°C the electrical conductivity drops by about 2 orders of magnitude between 4 and 10 bars confining pressure. One difficulty is that pore pressure is not known. Future experiments will include separate pore and confining pressure control so that more accurate conductivity measurements can be performed when entering the steam field.

CONCLUSIONS

Although porosities for the 918 ft graywacke sample are low, ranging from 1 to 6.5% for small plugs, statistical analysis of x-ray attenuation can discriminate between dry and saturated matrix. As preserved core is opened and dried to provide baseline data, estimates of the water content at the well head can be inferred from scans done soon after drilling (Bonner et al., 1995). Ultrasonic compressional velocity measured on whole core is somewhat lower than that measured for small plugs by Boitnott and Boyd (this volume). Velocity hysteresis occurs after drying, suggesting that permanent changes in structure result from dehydration. Extensive cracks-with lengths approaching the core diameter-can form during drying. These cracks form along preferred directions and appear in tomograms of dried core. Therefore, preserved core and careful handling is essential for measurements that depend on crack porosity. This conclusion is preliminary since most of the preserved core has not yet been opened, and is being reserved for careful measurements.

Electrical conductivity measurements demonstrate that there is little effect of pressure on conductivity. The pore structure of the unfractured matrix is not compliant. Large changes in conductivity occur when the temperature is increased to near boiling. This increase is probably caused by increased ionic mobilities in the brine pore fluid.

REFERENCES

Bonner, B.P., J.J. Roberts and D.L. Schneberk, Determining water content and distribution in reservoir graywacke from the northeast Geysers with x-ray computed tomography, Trans. Geothermal Resources Council, 18, 305-310, 1994.

Gunderson, Richard P., Reservoir Matrix Porosity at the Geysers from Core Measurements, Trans. Geothermal Resources Council, 14, PART II, 1661-1665, 1990.

Hulen, J.B. and D.L. Nielson, Sample handling, field procedures, and curation guidelines for The Geysers Coring Project, University of Utah Research Institute Report, ESL-94002-TR,1994.

Sears, F.P. and Bonner, B.P., "Ultrasonic Attenuation Measurement by Spectral Ratios Utilizing Signal Processing Techniques" IEEE Trans. on Geoscience and Remote Sensing ,GE-19 95, (1981) [UCRL-83679].

Bonner, B. P., J. J. Roberts, D. J. Schneberk, A. Marsh, C. Ruddle, and E. Updike, X-ray tomography of preserved samples from the geysers scientific corehole, Twentieth Annual Stanford Geothermal Reservoir Engineering Workshop, 1995.